Metrics for Measuring the Performance of Domestic Combustion Stoves: Towards a Shared Vocabulary

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Building a lexicon of agreed terminology for testing stoves

There is a need for well-defined metrics and methods for testing and certification of cookstoves, in terms of thermal efficiency, emissions of gases and particles, fuel consumption and possibly other criteria

Stakeholders of Improved Cookstoves

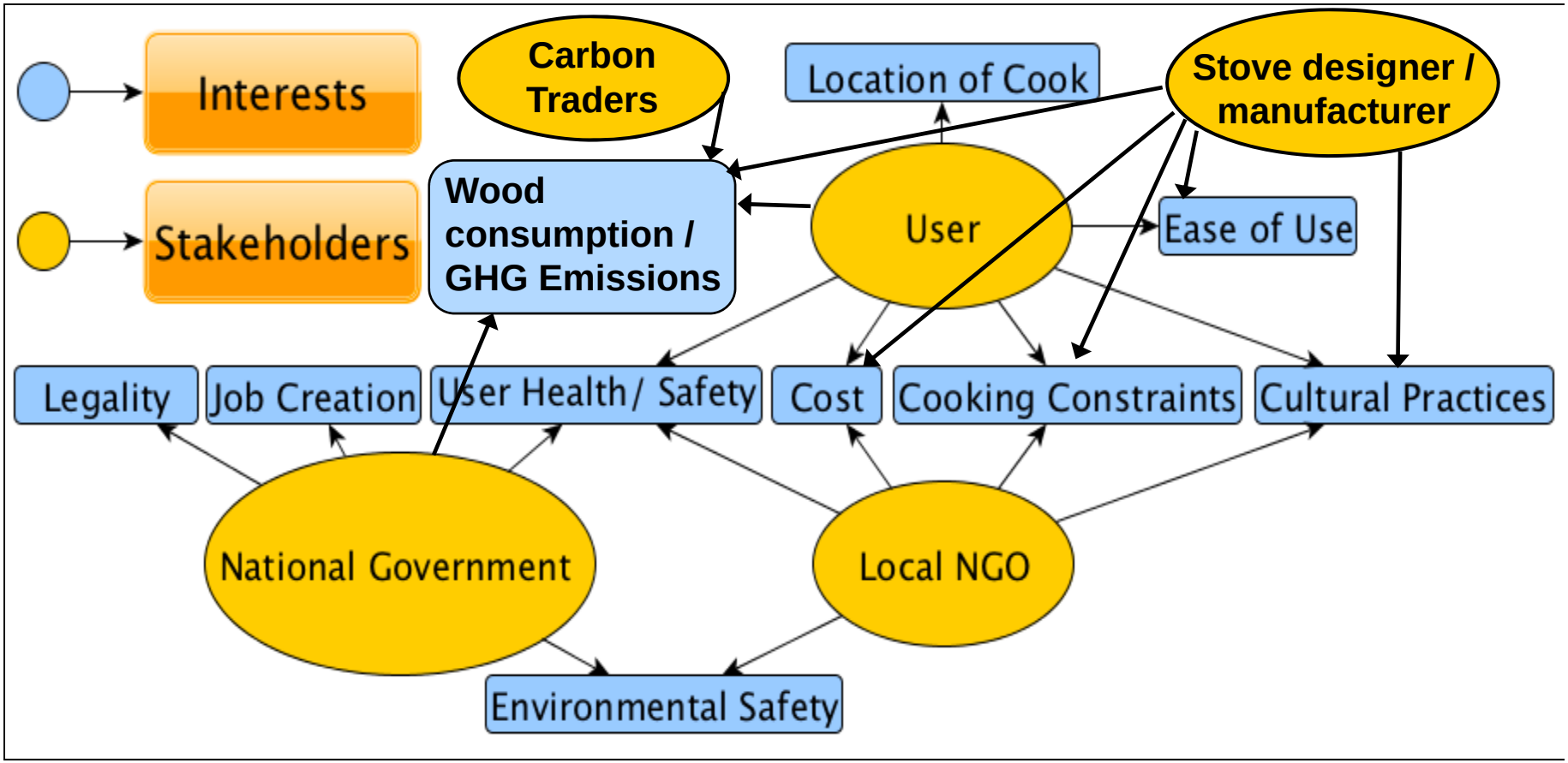

Figure credit: John Abelt, Caroline Bartholomew, Thomas Curley, Katelyn Ditzler, Dan Giannetto, Elizabeth Holohan, Chris Voltz, **January 11th, 2013 The University of Virginia, Project Proposal: STS 2500 / EVSC 1050**

Industry-wide assessment methods

- Who is going to use these assessments?
- Whose interests are being protected these assessments?
- What are the external benefits intended by the implementing agents?
- What metrics are most suited to these purposes and stakeholders?
- What is the most appropriate and affordable method of obtaining these metrics?
- What are the most appropriate performance target levels for each metric?
- What review process is in place that will update these metrics, methods and targets?
- What review process is in place to certify stove testing labs?

Basic Metrics

fuels

combustion

emissions

safety

More complex metrics

diverse cooking tasks

multiple fuels

affordability

traditions

stove acceptance

Highly technical abstractions

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Green House Gas mitigation assessments

- Certified Emission Reductions (CERs)
- precise and detailed verification of the continued use of certified stoves
- practices of users over multiple years
- expectations of stove programmes include local manufacture and job creation
- GHG reductions to meet national targets
- protection/conservation of forest resources.

Towards a Common Terminology

Boiling – suitable for defining task-based tests

Water Boiling Test – any test in which the heating of water is used as the surrogate to determine the transfer of heat from the fire bed to the target cooking vessel/surface

Rolling boil – task-based tests only.

Timing of boiling point is a problem unless continuous recording is part of test apparatus.

Change of boiling point temperature with altitude a minor complicating factor.

Water heating – suitable for fundamental performance assessment

e.g. thermal efficiency ➔ heating from 30°C to 70°C.
Allows good precision while minimizing corrections for evaporation losses.

Towards a Common Terminology

Simmering – is a task, boiling at reduced power.

Descriptive, qualitative term, not an exact scientific term.

Suggested definition:

A state of equilibrium in which the heat input is adjusted to keep the temperature close to or at boiling, ***with infrequent bubbles at the surface***

Frequency of bubbles can be measured in a lidded pot with a microphone (or a wooden spoon!)

Could become useful term for lower power operation.

Towards a Common Terminology

Thermal Efficiency – useful application of heat

One of the anchor concepts

- Can be applied at several different scales within the system of fuels/stove/user/environment
- Requires a comparison in some context
- The baseline must be contextually defined

Towards a Common Terminology

- Evaporation and possible chemical conversion of moisture in the fuel influence the available sensible heat, the exact properties of the fuel, chemical and moisture need to be specified as part of the thermal efficiency report.
- Combustion efficiency affects **emission**s most
- Thermal (heat transfer) efficiency affects **fuel consumption** most

Thermal Efficiency

Thermal Efficiency (TE)

$= (M_2 - M_1)*\sigma / [(T_2 - T_1)*(M_{pot}* \theta_{pot} + M_w* \theta_w)]$

where

M_2, M_1 are the final and initial mass of fuel,

σ is the lower heating value of the fuel,

T_2, T_1 are the final and initial temperatures,

$M_{pot, w}$ and $\theta_{pot, w}$ and the mass and specific heats of the pot and water respectively.

For practical purposes of not losing water mass and energy through evaporation, the final temperature should be in the range 60 to 70°C during this type of test.

Fuel Consumption

For fuel consumption, the quantity of fuel added for each cycle is the required metric. What do users do in practice? It matters!

Definition of fuel consumption:

The amount of new fuel required to initiate and complete a task within a sequence of repetitive uses

Residue of char or partially pyrolysed wood is a significant element of the calculation – is it discarded, or is ti used in next fire-making cycle?

- For calculating GHG emissions, the use of residual char for combustion or non-combustion use is an important factor in the calculation.

Fuel Efficiency

Fuel Efficiency – related to, but distinct from thermal efficiency.

Derived from ***fuel consumption***, for the improved stove and for the reference case.

Fuel efficiency (%) = $(M_{fuel\ old} - M_{fuel\ new})/ M_{fuel\ old} *100$

where $M_{fuel\ old}$ is the mass of a fuel batch for the reference stove, and $M_{fuel\ new}$ is the mass of a fuel batch for the improved stove.

Note that this definition, while it should make use of a standardized pot and water load (or other reference tasks), does ***not*** make use of the volume of water and is not indexed to the contents of the pot.

Emissions: Safety and health issues

Emissions - has safety and health issues

- Household Air Pollution (HAP) is addressed
- The monitoring of indoor or ambient concentrations in the breathing zone and reference to health-based air quality standards are adequate to establish the necessary causal improvement.

Emissions

Similar to thermal efficiency and fuel efficiency, **emission metrics** are defined separately for the **stove designer,** the **health** programme implementer; and the **CER** programme implementer.

Designer requires real time emission factors of gases and particles for the fuel/stove/pot combination

HAP risk assessment requires the total mass of emissions per fuel cycle (instantaneous values are not required)

Dosing short/long term may alter this view.

CER implementer requires integrated GHG emissions over entire cycle (including burnout after cooking).

Towards a Common Terminology

For designers

- Real time or instantaneous emissions refers to the emissions calculated over a short time interval: 10 seconds
- Emissions are compared with the combustion conditions prevailing at the time
- Design changes are based on what is learned from the analysis of this information

Emissions for Health

Requires emissions per combustion cycle

Includes fuel, sequence of lighting, cooking

Obtained by observation of the partner community

Pre-determined, complex task metrics are usually not suitable and obscure rather than assist comparisons between stove products.

Performance metrics – from a user's perspective

- Ease of ignition
- Time from lighting to first use of stove (lead time) minutes
- Time from placing pot to boiling temperature (for typical volume, expressed per liter) minutes/litre
- Duration of useful burn (must be longer than time to complete cooking) minutes
- Number of pots N
- Fuel efficiency/improvement g/task; % savings
- Reduction in indoor fumes (smoke and gases) % reduction
- Fuel types accommodated, description
- Fuel preparation; time required per burn cycle
- Safety rating
- Installed cost $ + time
- Durability: months/years

Performance metrics – from a WBT's perspective

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- Temperature-corrected time to boil a standard mass of water [minutes]
- Heat transfer efficiency, per cent (%)
- Fuel burning rate [g/minute]
- Specific fuel consumption [g/litre]
- Temperature-corrected specific fuel consumption [g/litre]
- Temperature-corrected specific energy consumption [kg/litre]
- Firepower kW
- Turndown ratio [kW_1/kW_2]
- Mass of emissions of CO, CO_2 and PM per litre of a water heating and boiling task [g/litre]
- Mass of emissions per kg of fuel [g/kg]

Performance metrics – from the program and Donor's viewpoint

- Needs are: transparency and accurate assessment for them to be able to make informed choices, local relevance, replicability and precision
- Gaseous and particulate emissions per standard task [mg/task]
- Fuel consumption per standard task [g/task]
- Distributed cost and expected working life, $, months/years
- Stability, safety and durability, tipping, cuts/burns, strength/resistance
- Suitability to the local conditions (tasks and fuels):
  Locally acceptable? Fuels available?

Performance metrics – from a National Regulator's perspective

- Seeking to protect citizens from harm or false claims
- Metrics: gaseous and particulate emissions per Mega-Joule (impact on the local environment per useful MJ of energy delivered), g/MJNET, mg/MJNET
- Net Fuel efficiency (impact on the fuel resource), % of energy utilized
- Minimum power; maximum power, [kW], [kW]
- Minimum thermal efficiency [%], stability, safety and durability, tipping, cuts/burns, strength/resistance
- Resistance to conflagration, tip-over test

/continued

Performance metrics – from a National Regulator's perspective (continued)

- Sustained performance over time, {nn} hours burn test
- Random testing for repeatability, random samples from supply chain
- Certification of the design drawings, conformity of the product, compare product with drawings
- Identifying marks and traceable origin, manufacturer, date, serial number, batch number, fuel, power
- Written and pictographic instructions and tools provided, samples provided, tools tested by using them.

Information requirements of the manufacturers and distributors

- Published standard testing method, National Standard
- Project or National Standard performance requirements, details of compliance issues
- Gaseous and particulate emissions per Mega-Joule (impact on the local environment per useful MJ of energy delivered), [g/MJNET], [mg/MJNET]
- Net Fuel efficiency (impact on the fuel resource) [% of raw fuel potential applied during cooking]
- Information regarding the performance preferences of the customers, social science impact assessment

Information requirements of stove designers

- Emission factors, continuous measurement
- thermal efficiency,
- system and heat transfer
- time to boil, per litre
- power [kW]
- duration of usable cooking temperature
- fuel consumption to boil, specific, at max power
- fuel consumption per burn cycle,
- dry fuel energy consumption, specific, at simmering power [Joules/cm^2 of pot contact area]

Information requirements of investors, multi-lateral global agencies and policy makers

- There is a mismatch between the 'metrics' needs of different institutional stakeholders.
- There is a mismatch between the metrics provided by the tests in common use and the needs of both policy makers and funders of stove programmes.
- The commonly available performance information is from en earlier policy environment.
- Testing outputs should be driven by policy, with metrics defined from basic physics principles
- There is a fairly easily defined divide between metrics needed for product development and health/foresty/GHG program implementation.
- There are many shared metrics. The protocols should be built around them so as to provide precise and consistent evaluations.

Conclusions: Metrics for Measuring the Performance of Domestic Combustion Stoves: Towards a Shared Vocabulary

- A lexicon should be compiled and maintained on an open access platform (a GACC wiki), as an ongoing community based activity.
- The stakeholders in or reasons for a particular metrics should be part of the definition.
- The list should be inclusive of all commonly used terms, rather than exclusive of overlapping or contradictory terms.
- Once definitions of certain terms ad metrics converge, transfer to a permanent agreed lexicon.
- Would the GACC be willing to host this lexicon?

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